



How to make modal shift from road to rail possible in the European transport market, as aspired to in the EU Transport White Paper 2011

Dewan Md Zahurul Islam¹ · Stefano Ricci² · Bo-Lennart Nelldal³

Received: 20 November 2015 / Accepted: 17 May 2016 / Published online: 7 June 2016

© The Author(s) 2016. This article is published with open access at SpringerLink.com

Abstract

Introduction The total demand for freight transport in Europe has increased significantly in recent decades, but most of it has been handled by road transport. To fulfil the modal shift targets set in the EU White Paper 2011, it will be necessary to double rail's market share from today's 18 %, by 2050. Translating this into reality means rail will have to handle 3 to 4 times the cargo volume it does today. With this in mind, the paper develops a vision of an efficient rail freight system in 2050.

Methodology To achieve the above objective, the research applies literature survey and group discussion methodology and applying a system approach. Keeping on board the EU Transport White Paper 2011 modal shift targets, as well as future freight demand and customer requirements, the current research attempts to answer the following three critical questions:

- How can rail offer the quality of service that will attract customers and fulfil the targets?
- How can rail offer its customers a price that is competitive with road?
- How can rail offer the capacity to meet the increased demand from modal shift?

Results The authors find that the service quality can be improved by better planning, application of appropriate ICT-systems and adoption of an integrated supply chain approach. A more customer-orientated service can also be achieved by further deregulation of rail. There is also an urgent need for a faster implementation of Rail Freight Corridors (RFC). As well as liner trains, future rail freight services should be offering end-point trains, with semi/fully automated loading/unloading equipment in hub-terminals, as well as terminals at sidings to improve the availability of intermodal operation.

Conclusion To offer a competitive price and reliable service, a reduction in operating costs will be vital by implementing a number of measures, including operation of heavier and longer trains, wider loading gauge, higher average speed, and better utilisation of wagon space and all assets. This will bring increased capacity, as well as better timetable planning, signalling systems and infrastructure improvements.

Keywords Rail freight · Customer requirements · Improvements · Modal shift · White paper 2011 · 2050 · Europe

This is part of Topical Collection on The Future of rail freight transport and logistics

✉ Dewan Md Zahurul Islam
dewan.islam@newcastle.ac.uk

¹ NewRail - Centre for Railway Research, Newcastle University, Newcastle upon Tyne NE17RU, UK

² DICEA "Sapienza" Università di Roma, 00184 Rome, Italy

³ KTH Royal Institute of Technology, 100 44 Stockholm, Sweden

1 Introduction

Transport is an essential service sector, consisting mainly of road, rail, waterways and air, which facilitates mobility and growth for regions and countries. The necessity for an improved and integrated transport sector has been intensified by the expansion of the European Union, due to the fact that today's European transport system originates from nationally focused systems, developed over many years, with different technical and operational abilities,

standards and service qualities. In recent years, in particular since 1991, the European Commission (EC) has made efforts to change this nationally focused and segmented approach - particularly acute in the rail sector - into a Europe-wide, integrated and interoperable transport system. Examples of such efforts in the rail sector take the form of Directives and Railway Reform Packages, including Directive 91/440/EEC that signalled an important turning point for rail liberalisation in Europe. Another important milestone was the First Railway Package, consisting of three Directives:

- Directive 2001/12/EU that is designed to clarify the formal relationship between the state, the infrastructure manager and the railway undertakings (operators);
- Directive 2001/13/EU that sets out the conditions for freight operators to be granted a licence to operate services on the European rail network; and
- Directive 2001/14/EU that introduces a defined policy for capacity allocation and infrastructure charging [40].

Reform efforts were continued in the Second, Third and Fourth Railway Packages, where the Directives were subsequently revised to make the European rail freight (and passenger) sector fit to meet the needs of operators and customers. Ultimately, the reform measures were aimed at creating a market environment where rail freight operators can gain access, compete and gain due market share, and contribute to a sustainable society [10, 11]. Towards this aim, on 28 March 2011 the EC published its Transport White Paper “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system”.

In addition to competitiveness, another important EC policy objective is to achieve a long-term, sustainable transport system. To achieve this the EC has set the transport sector reduced emissions targets. The goals set for the rail mode can be summarised as:

- 30 % of road freight over 300 km should shift to other modes, such as rail or waterborne transport, by 2030, and more than 50 % by 2050, facilitated by efficient, green freight corridors.
- By 2050, a European high-speed rail network should be completed; the length of the existing high-speed rail network should triple by 2030 and maintain a dense railway network in all Member States.
- By 2050, the majority of medium-distance passenger transport should be by rail [11].

Bearing these targets in mind, an insight into the transport sector is crucial - especially for rail - and the current research attempt to identify current trends, quantify future demand,

identify customer needs and suggest ways to meet them. Three critical questions for the rail sector are:

- How can rail offer the quality of service that will attract customers and fulfil the targets?
- How can rail offer its customers a price that is competitive with road?
- How can rail offer the capacity to meet the increased demand from modal shift?

The current research attempts to determine, from a technical and operational point of view, how to develop the rail freight system to fulfil the targets, from today and beyond the state-of-the-art.

1.1 Objective

The current research evaluates the major trends in the European rail freight system, forecasts future demand levels and categories, and identifies customer needs along with suggested ways to make the European rail freight system capable of meeting them, by 2050. The main objectives of this research are to:

- Elaborate the state-of-the-art of the European rail freight system;
- Briefly describe some scenarios for rail freight demand up to 2050, using extracts from forecasts and taking into account the EU white paper;
- Analyse existing and expected future customer requirements for different goods types;
- Identify measures that will make rail more cost effective, but not to make socio-economic calculations;
- Analyse progress beyond the state-of-the-art for vehicles, intermodal systems and operation principles and identify remaining gaps towards 2030/2050;
- Provide an insight into an efficient rail freight system that can fulfil EU targets, by 2050.

1.2 Methodology

The current research applies a qualitative methodology to elaborate the state-of-the-art of the European rail freight system, to identify the future needs to 2050, and to suggest some steps to meet those needs. Literature surveys are conducted, reviewing the current body of knowledge in the field, such as relevant scientific conference and journal papers, publicly available reports from both EC and national Government funded projects, and working documents that have already been published, are in the process of publication, or whose results are available to the researchers due to their involvement in other research.

To achieve a comprehensive scenario and to complement the literature survey findings, the research also conducted two group discussions. [26] suggests that a group discussion encourages cooperation among members to find a solution to a dilemma. [6] used a small (2–3 participants) discussion group. [26] warns that a large group discussion may form a barrier to achieving consensus. Considering these suggestions and applications, the current research used two medium sized groups of 5–6 participants, made up of the researchers' peers in the academic, policy, technical and operational areas of the rail freight sector. The group discussions were held on 21 January 2014 in Rome, Italy and on 23 September 2014 in Berlin, Germany. The early findings of the research were presented to the first group of six participants, followed by a brain storming session. The objectives were to obtain feedback on the progress of the research so far, to identify any gaps, and to take direction on any missing data. The second group discussion, held in Berlin with five participants, evaluated the most important development trends, the long term (2050) and medium term (2030) requirements, and what is still missing to achieve the modal shift policy objectives. A specific objective of the second group discussion was to gain consensus on specific topics and sub-topics (see Table 1, at the end of this paper) on the direction of the future rail freight system of 2030 and 2050, with the vision of 'incremental' (or intermediate) and 'step' change in the rail freight sector.

In the freight transport system, technical development has been generally incremental; for example, the performance of locomotives has improved gradually from steam. The tractive power of the locomotive has often determined the change needed for improved operation of trains and infrastructure and here a 'step' or 'complete' change in the system can be argued for in the long term (e.g. 2050). For example, we can see that the brake control should be changed from 'pneumatic' to 'fully electric', rather than the intermediate change to 'radio controlled end-of-train (EOT)'. From the two group discussions, there was consensus that there is no 'one correct answer to every question', because market development trends will evolve over time and crises (e.g. the ongoing economic recession since 2008) will interrupt forecasted or expected development.

An important aspect of this research was the necessity to restructure the information collected from different sources to make it compatible, comparable and consistent, Europe-wide. Such necessity arises when there is a problem of selecting the most adequate and appropriate information collected from varying sources, and in some cases contrasting findings, as well as information about ongoing developments on which publications are not yet publicly available. The current research recognises that, with a long term perspective such as 2050, it is necessary to not only investigate what is on the market today, but also what may come onto the market from a world-wide, best practice point of view - not only for and

from the railway sector, but also for and from other modes and the industry as a whole.

2 Rail freight trends in Europe

2.1 Freight transport volume 1970–2011

The total transport demand for the EU15 (consisting of so-called 'old' members, before 1995) has been analysed from 1970 to 2011; for the EU12 ('new' members, since 1995) and EU27 (consisting of member countries, 2013) the date range is 1995–2011. Total demand and rail market share have been calculated using the sum of rail, road and inland waterways.

Between 1970 and 2007 total freight transport volume, in billion tonne-kilometres in the EU15, increased by an average of 2.5 % per year, then decreased until 2011. Most of the increase volume has been transported by road, resulting in its significantly increased market share, from 52 % in 1970 to 78 % in 2007. Rail freight volume has been either constant or decreasing over the same period; overall rail market share decreased from 36 % in 1970 to 15 % in 1995, though it then stabilised and has slightly increased in recent years.

2.2 Transport modes and their market shares

Road transport is available in all countries and totally dominates short-haul (in particular <100 km). A trucking service is also an essential component of a rail and waterways door-to-door inter-modal service, for pickup at origin and delivery at destination. The trucking industry carries a significant volume over very long distances and offers a competitive and reliable service.

Analysis of the 'EU Transports in figures - statistical pocketbook 2014' [13], shows that rail is available in most EU countries, but that its market share varies widely. The highest transport volumes are in Germany and Poland, but rail's market share is highest in Switzerland and Austria. Inland waterways - rivers and canals - are available and used in countries like Germany, France and the Netherlands, mostly for bulk transports, as well as feeder transport of containers to and from big international ports, like Rotterdam and Antwerp.

2.3 Rail freight volume

Rail freight in EU27 decreased from 551 to 526 billion tonne-kilometres between 1970 and 1990, decreasing further to 404 in 2000, with the removal of the rail monopoly in EU12. The next years saw an increase to 440 by 2008 but, despite continued improvement in EU12, the onset of economic crisis brought an overall decrease in EU27, to 420 in 2011 [12] (see Fig. 1). Most of the freight volume (59 % in tonnes) carried by the railways in 2012 was domestic (with 36 % international and 6 % transit freight). The share of

Table 1 Currently used equipment, methods and common standard, with required future incremental and total system changes

Equipment	Common standard	Incremental change ^a	System change ^a
Wagons			
Running gear	Different	50 % track-friendly	All track-friendly
Brakes	Cast brakes	LL brakes	Disc brakes
Brake control	Pneumatic	Radio controlled EOT	Fully electronic
Couplers	Screw couplers	Automatic couplers on some trains	Automatic couplers on all trains
Max Speed	100 km/h	120 km/h	120–160 km/h
Max Axle load	22.5 tonnes	25 tonnes	30 tonnes
Floor height lowest	1200 mm	1000 mm	800 mm
IT-system	Way-side	Some in wagons	All radio controlled
Locomotives			
Tractive effort kN	300	350	400
Axle load	20 tonnes	22.5 tonnes	25 tonnes
Propulsion	Electric	Some duo-locos	All duo-locos
Fuel	Diesel	LNG/Diesel	LNG/electric
Drivers	Always drivers	Some driverless	All driverless
Trains			
Train lengths in RFC	550–850 m	750–1050 m	1050–2000 m
Train weight	2 200 tonnes	4 400 tonnes	10 000 tonnes
Infrastructure			
Rail Freight Corridors	18,000 km	25,000 km	50,000 km
Signalling systems	Different	ERTMS L2 in RFC	ERTMS L3 in RFC
Standard rail weight	UIC 60 kg/m	70 kg/m	70 kg/m
Speed standard freight	100 km/h	100–120 km/h	120 km/h
Speed fast freight	100 km/h	120–160 km/h	120–160 km/h
Traffic system			
Wagonload	Marshalling - feeder	Marshalling - feeder	Automatic marshalling
		Some liner trains	Liner trains - duo-loco
Trainload		Remote controlled	All remote controlled
Intermodal	Endpoint-trains	Endpoint-trains	Endpoint-trains
		Liner trains with stops at siding	Liner trains fully automated loading
High Speed Freight	National post trains	International post and parcel trains	International post and parcel train network
IT /monitoring systems			
	Some different	Standardised	Full control of all trains and consignments

^a Adapted to market needs on each product and line

international transport slightly decreased, and domestic transportation slightly increased, from 2004 to 2012 (see Fig. 2).

Rail freight operational models comprise different products: trainload, single wagon load and intermodal. These models have approximately 50 %, 25 % and 25 % respectively of the tonne-kilometres in Europe. ‘Trainload’ refers to dedicated trains operating for a specific company, or cargo type, e.g. ore, coal and timber trains. ‘Wagonload’ refers to conventional SWL (Single Wagon Load) from customers, transported by a feeder rail freight operator to a nearest or suitable marshalling yard or terminal for consolidation, from where they are transported by long distance block or shuttle trains to the destination terminal or marshalling yard, and then on to

destination by feeder train transport. ‘Intermodal traffic’ refers to cargo in containers, swap-bodies and trailers used for feeder transport, that are loaded on trains at terminals for long-distance transportation. SWL volume has gradually decreased in favour of trainload and intermodal [7, 18, 39]. In contrast, the freight volume carried by intermodal train has increased, mainly due to the higher flow of containers through maritime ports.

2.4 Rail market share in different countries

The overall decrease in rail’s market share has been heavily influenced by losses in the new member states (EU12), where

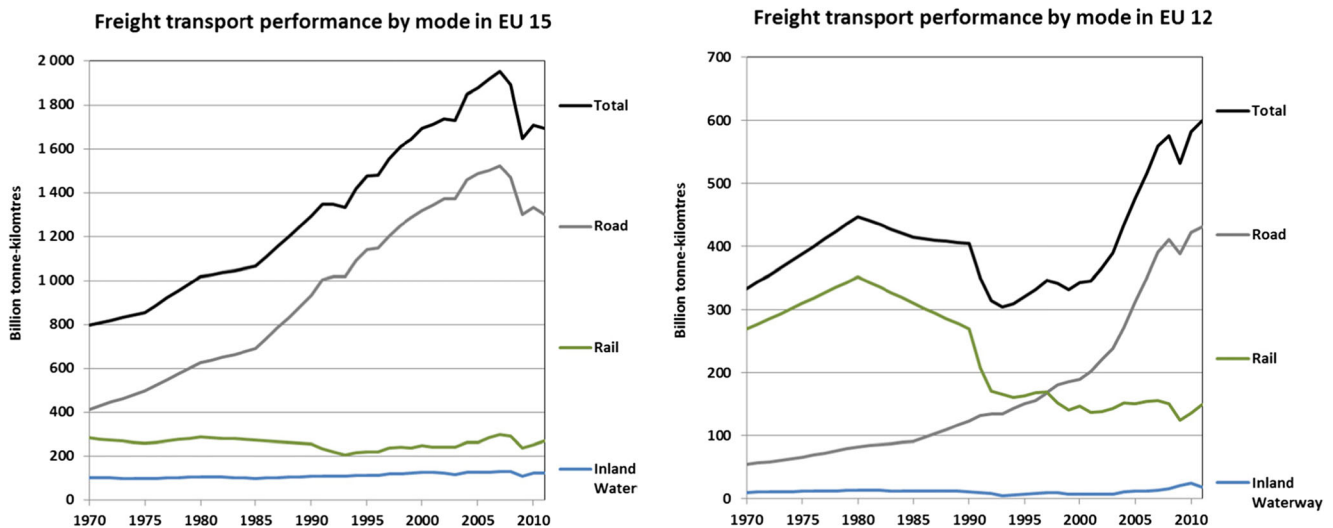


Fig. 1 Development of the total demand and split by mode (tonne-kilometres), for EU 15 and EU 12. Data source: ([12] with completing calculations for some years)

it decreased rapidly and deeply from 51 to 23 % (in tonne-kilometres) between 1995 and 2009, following the abolition of the railways monopoly. Contrasting trends can be observed in the EU15, where rail's market share has remained fairly stable, at about 15 %, since 1995. In recent years, rail's share of the market has increased slightly, in both EU12 and EU15.

To analyse further, specific countries have been arranged by EU15 or EU12 (see Fig. 3) and then by rail market share from highest to lowest (see Figs. 4 and 5). For broader understanding, non-EU-members Switzerland and Norway are also included. In some countries, rail has long enjoyed a high market share: Switzerland 45–50 % and Austria 30–40 %, of which a significant volume can be attributed to transit traffic. Sweden and Finland also have higher rail market shares, with 25–35 %. In Germany, rail's share has increased from 19 % in 1995, to 23 % in 2011. The UK, Denmark and the Netherlands have also seen an increase in rail, but from a very low level. Significantly, in these high rail-share countries, rail lost market share every year after the end of World War II, until rail's

fortunes reversed, in recent decades. These are the top-ranked countries in the Rail Liberalisation Index 2011 [14]; their success can be partly attributed to the reformed market environment - with new private companies entering the market and competing with the incumbent - as well as the pressure on the incumbent railways to be more efficient, through higher asset and human resource utilisation. In some countries (Germany, Austria, Switzerland), truck-fees may also have affected the modal split towards rail, but this development is not dramatic. Overall, the latest situation in the rail freight sector in the EU15 may be indicative of a reversal of the previous trend of a continuously decreasing market share.

By contrast, in some EU15 countries, rail's share has decreased during the same period. For example, in France it has decreased from a relatively high level of more than 20 %, to 15 %. From a low level of approximately 10 %, rail share has decreased even further, to less than 5 %, in Spain, Luxembourg and Ireland - countries at the bottom end of the Rail Liberalisation Index 2011 - suggesting that the decline can be attributed at least in part to the lack of railway reform. In recent years, rail's market share in these countries has either stabilised or slightly increased.

In the EU12 in 1995, rail held a very high share of the freight transport market in several countries. For example, in Latvia, Lithuania and Estonia, rail had 70–95 %, which had decreased to 55–65 % by 2011. A similar fall has been seen in Poland, Slovakia and the Czech Republic, where 40–50 % has decreased to 20–30 %, by 2011. Interestingly, in all these countries, rail market share seems to have fluctuated or stabilised, over the last 5 years. In Bulgaria, Slovenia, Croatia and Hungary, rail's market share of between 35 and 60 % has declined to 20 % or less, while in Turkey it has remained stable, at a low level of approximately 5 %.

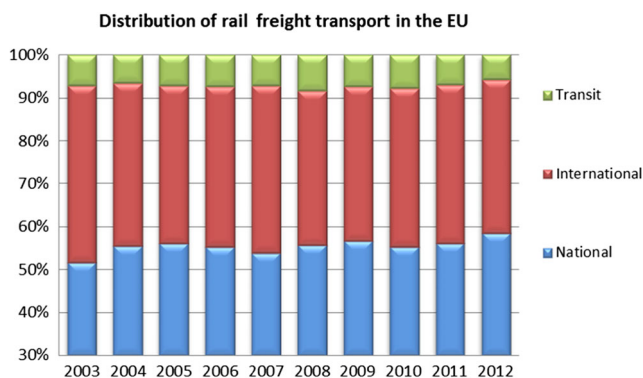


Fig. 2 Domestic, international and transit transport by rail; distribution of tonnage in EU27

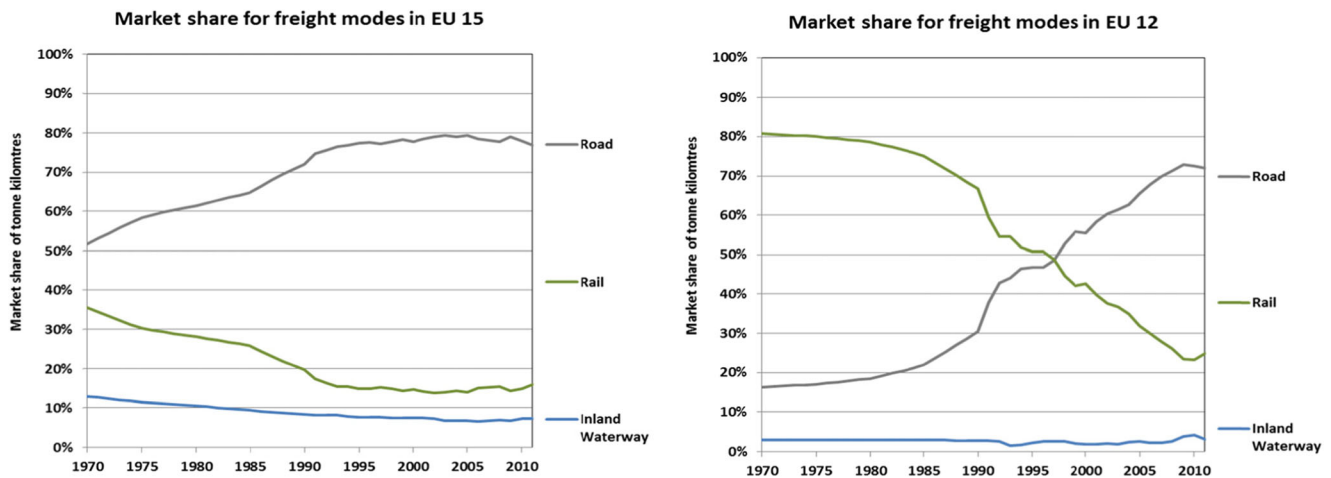


Fig. 3 Development of modal split (tonne-kilometres) in EU15 and EU12. Data source: [12]

3 Forecasts of future rail freight demand in the EU up to 2050

3.1 Total demand for freight transport

A number of forecasts have been conducted for freight transport in Europe, with different scope and objectives and with different perspectives (e.g. Primes, TREMOVE, iTREN, TRANS-visions, TOSCA, D-RAIL, and SPECTRUM). The findings of more recent forecasts are analysed and presented here, e.g. [9, 17, 20, 22, 32, 35]. Most of these forecasts include road, rail and inland waterway, but some also include maritime transport. Despite the ongoing European economic recession since 2008, the forecasts are made assuming economic growth in the long term. Another important assumption used in these forecasts is the EC Transport White Paper target for modal shift, with the recognition of current recession in the data analysis. This research has analysed these forecasting studies, using the TRANS-TOOLS modelling tool, with a long-term time horizon (e.g. up to 2030 and/or 2050).

3.2 Future freight transport demand per mode

Most forecasts show small differences and changes in modal market shares, in their business-as-usual scenarios. The findings of the three forecasts are elaborated below.

The D-RAIL study [9] forecasted future rail freight demand assuming three different scenarios: 1) Reference scenario - with no change to the infrastructure, policies and other trends of the current rail system; 2) White Paper High scenario - modal shift of 50 % by 2050; and 3) White Paper Low scenario - modal shift of 30 % by 2030). The study shows, in the Reference and Low scenarios, a total growth of 65 % and 99 % respectively, between 2010 and 2050. The growth for the High scenario is more than double (216 %) the Reference scenario. The countries that show the highest relative growth are in the EU15, with Germany and Italy maintaining the highest positions. In the EU12 group, the higher flows originate from Poland, the Czech Republic and Romania, representing 60 % of the total EU12 demand [19].

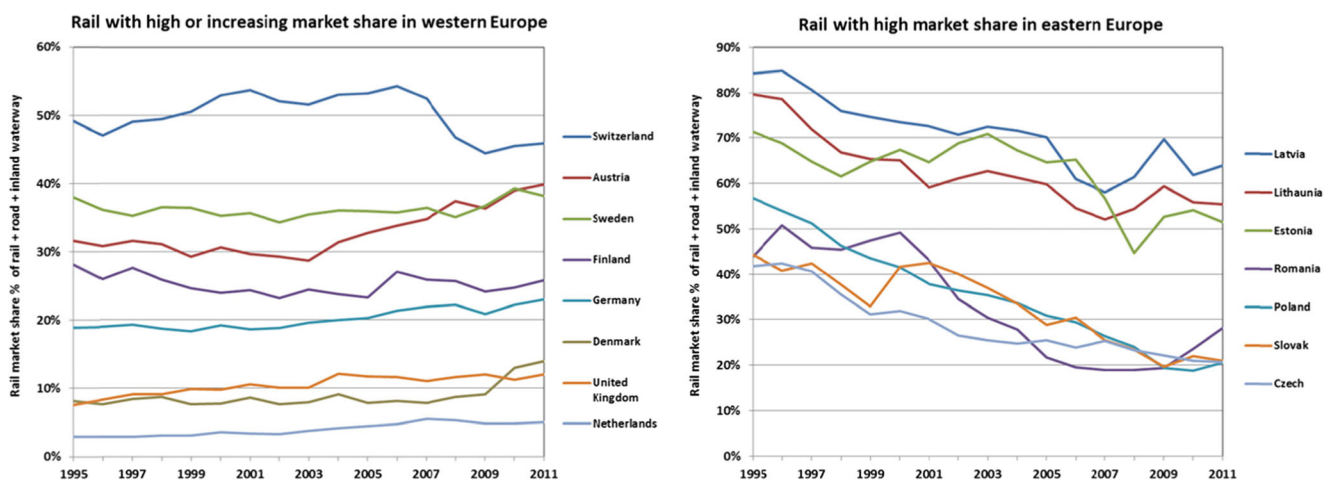


Fig. 4 Left: Development of rail freight market share (tonne-kilometres) in EU15 countries (plus Switzerland) with high or increasing market share. Right: Development of rail freight market share (tonne-kilometres) in EU12 countries with high market share. Data source: [12]

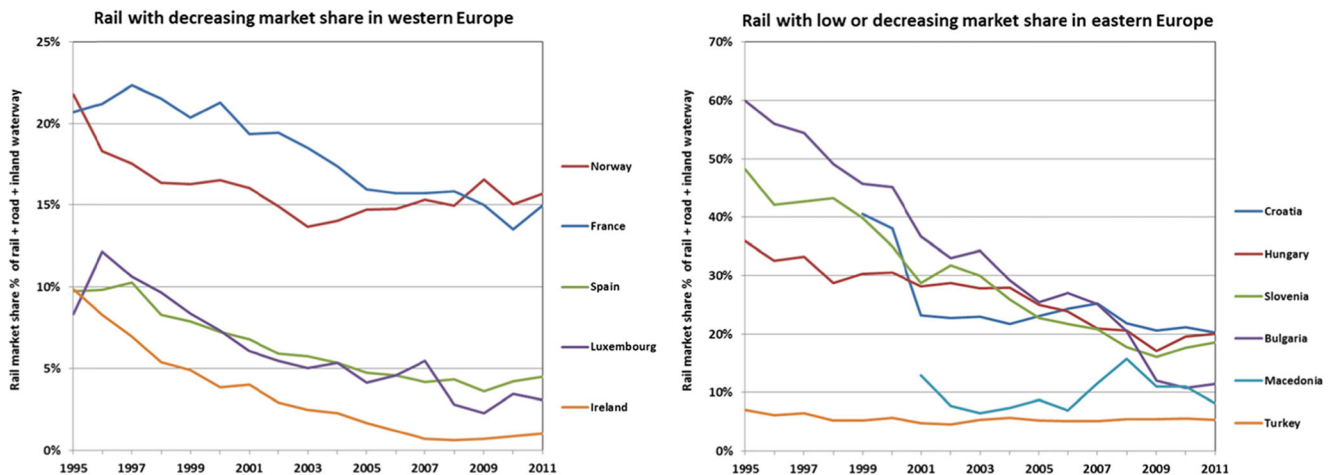


Fig. 5 Left: Development of rail freight market share (tonne-kilometres) in EU15 countries (plus Norway) with decreasing rail market share. Right: Development of rail freight market share (tonne-kilometres) in EU12 countries with low or decreasing rail market share. Data source: [12]

The transport demand analysis in the SPECTRUM study included LDHV (Low Density High Value) goods, which include agriculture, foodstuffs, metal, chemicals and other products. The majority of these goods are transported by truck and the study argues that it from road that the shift to rail will have to take place [22, 32]. The SPECTRUM study analysed the potential market for LDHV goods, currently transported by road over distances of 200+ km, which has the potential to move to rail transport. It further noted the most important countries/regions, and a pattern of specific industries, for example a concentration of metal products in Italy's automotive industry and of agricultural products in France, the EU's leading agricultural power (with around one third of its agricultural land). LDHV goods transported by road totalled 3.9 million tonnes in 2009 and are forecasted to grow by 53 % by 2030, reaching a volume of 5.9 million tonnes. The transport by road of metal products and other types of products is expected to have the highest increase. The total volume of rail freight transport in EU27 and Switzerland is estimated to increase from 1.1 billion tonnes in 2009, to 1.5 billion tonnes of LDHV cargo in 2030. The study expected that, with the structural changes in the economy and demography, the transport of bulk commodities would decrease in future.

With base year 2010, the TOSCA study [35] - without taking into account the EU Transport White Paper 2011 targets - forecasts that the total freight transport demand, in tonne-km, will increase by 50 % by 2050. The market shares will be rather stable, with 81 % for road in 2010 and 82 % in 2050 and 19 % for rail in 2010 and 18 % in 2050. Thus the forecasted freight volume by road will grow slightly faster than rail; this shift in favour of road - the reverse of EC Transport White Paper policy - is probably a consequence of different economic development for various sectors and commodities and the actual mix for different modes.

The TOSCA forecast has been elaborated with a "best practice rail" scenario [29] with influences from the US and Switzerland. This leads to an increased market share for rail - from 19 to 45 % in the rail-truck market - and an increased average rail transport distance from 304 to 499 km (see Fig. 6). This is 3.6 times the 2010 level and 2.5 times the 'business as usual' scenario, which is a challenge for capacity. By achieving this freight volume, rail can reduce EU transport GHG emissions over land by some 20–30 %, compared with a 'business as usual' scenario.

4 Customer requirements for future rail services

4.1 Customer requirements versus current rail freight service structure

The freight transport market has changed, from large quantities of bulk being transported by block trains, to smaller, more frequent shipments with a higher value and a faster and more reliable delivery requirement. The development of the single European market, regularly extended to new member states joining the EU, has boosted another type of customer demand for pan-European freight traffic.

The European rail freight industry, developed on a domestic focus with powerful incumbent railway undertakings, has not yet developed the necessary collaborative or integrated approach needed for the kind of total pan-European transport chain widely practiced by maritime shipping lines, for example. There are various reasons for this, including the fact that the multiple actors in multimodal transport chains have, at times, opposing interests. This, coupled with the high level of entry barriers faced by private new entrants, has failed to generate the development of industrialised, pan-European services to respond to market needs. Moreover, no modern

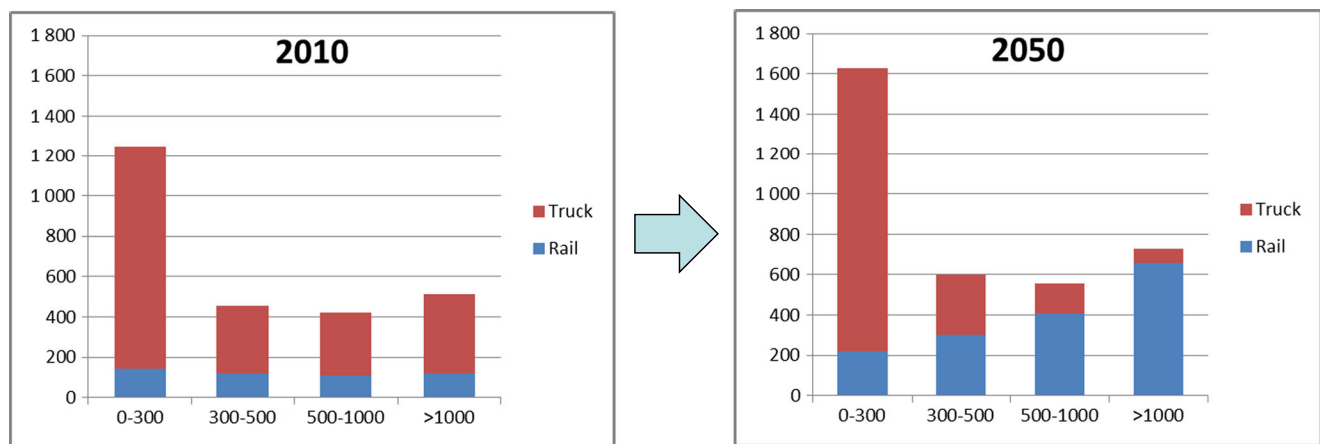


Fig. 6 Mode shift according to the EU white paper (analysing data from TOSCA forecasts with TransTools). Source: [29]

studies of this market have been conducted to evaluate its evolution, anticipate the needed revolution, or suggest new business models suitable to face the challenges due to, among other things, the protectionist attitude of the incumbents towards their market share. The bundling of the various categories of traffic (bulk, containers), the creation of efficient nodes to de-bottleneck by optimising the use of existing infrastructure, the development of fully interoperable Trans-European Rail Freight Corridors with a powerful governance platform, and coordination with national infrastructure managers, are all progressing too slowly. Overcoming the patchwork of national safety rules, through powerful action by the European Railway Agency (ERA), is progressively arriving at an urgent need to increase the pace. All of these elements have hindered the introduction of pan-European rail services.

4.2 The nodes-and- links concept for door-to-door rail freight service

The maritime shipping industry has, for many years, applied the ‘hub-and-spoke’ or ‘nodes-and-links’ concept, integrating multiple actors in one transport chain to achieve cost- and time-effective services. The concept is still at an early stage of development and application in the rail freight sector. The nodes-and-links concept encompasses various types of terminals, connecting each other as well as cargo origins and destinations, such as hubs, marshalling yards, freight villages, sea ports, dry ports, intermodal, conventional and multimodal terminals, and industrial and logistics zones [16, 38]. The nodes have to be close to a production and/or large consumption area and at corridor crossing points [21]. They have to: transform the traditional transit function over normal working hours into value-added, round the clock transit, by quick transfer between modes and/or train to train; achieve a high fill coefficient of trains or last mile transport; have a high degree of reliability for the end customer; and the ability to find the best connection to reach the end terminal through integration into

the whole network [1, 15]. These represent the key elements that contribute to managing transport networks efficiently.

4.3 Rail freight customer requirements

Through interviewing shippers and operators, the SPECTRUM study [22] identified the following shippers’ requirements (in order of importance):

- *Reliability of service:* Rail transit time (origin to destination, not just terminal to terminal) has to be competitive with road. However, consistently and unfailingly reliable transport (i.e. arriving at the agreed time, in full) is for many shippers even more important than the transit time itself.
- *Costs of door-to-door delivery:* Rail transport is often, but not always, more expensive than road transport, especially for relatively short distances and for door-to-door service. Low operational costs can be achieved by combining rail volumes on a corridor and by intensive use of the rolling stock and traction assets and thus can offer competitive (to road) freight pricing.
- *Service availability:* Service availability at both origin and destination is very important. Although rail is not able to compete with road transport in terms of flexibility, which is an important key to ‘service availability’, the frequency of a service in a day or week can complement this aspect.
- *Safety and security:* Reducing the chance of losses, theft and damage. This is especially important for the transport of high value goods. In general, rail freight transport has a competitive advantage over road transport with regard to safety (less chance of shifting in wagons) and security (less chance of theft).
- *Environmentally friendly transport service:* Many customers increasingly want environmentally friendly transport service but are unwilling to pay more for it. Considering this as an increasing trend, rail has an advantage over other modes to offer sustainable service.

For many customers, the most important need is a reliable transport service that results in reduced inventories and related costs. Considering the current and future commodity types to transport, customer needs can be summarised in a few points:

- Competitive cost for a reliable service (that can be measured by on-time arrival and departure of the service just-in-time);
- Easy access (measured by time taken by trucks, rail and waterways transport in terminals to pick up and deliver);
- Accurate information provision (for example, frequency of service, estimated time of arrival ETA versus actual arrival time);
- The adaptability of the service, at short notice, to the variations in volume that can occur quite suddenly (measured by time taken).

5 Technical needs for an improved rail freight system

5.1 System capacity, utilisation and improvement

Railway rolling stock comprises all vehicles including locomotives, coaches, and wagons that move on a railway system. From a freight train operator's point of view, we can consider two aspects: train capacity and wagon capacity. The train capacity is dependent, among other things, on the length of the train, as well as loading capacity (i.e. how much cargo can be carried). The capacity of a train can be broken down into two parts: volume (cubic) and mass (tonnage) loading capacity [2]. The cubic and tonnage capacity per train, together with higher average speed (may mean lower requirement of rolling stock for a certain amount of transport needs) drive both efficiency and higher capacity utilisation, since high fixed capital or 'personnel' costs per train contribute significantly to reducing the operational cost of a service. For the railway system as a whole, the loading capacity per train, multiplied by train frequency, determines the overall system transportation capacity [4]. Moreover, the loading capacity per train can be linked to axle load. The loading capacity per wagon is dependent on the number of axles, axle load, wagon tare mass, as well as the volume (cubic) and density (tonnage) of the cargo. The loading capacity per train can be limited by its useful volume, for example in the case of low-density voluminous commodities, or by its load (mass) limit, for example in the case of high-density heavy commodities.

The utilisation of capacity is as important as the system capacity itself. For example, to reduce the operational cost and to offer a competitive price to customers, the utilisation of wagons and trains must be improved, both by advance and proper planning and by improving the technical aspects. One example of technically improved utilisation is the VEL

wagon, which is a 26 m long wagon with two bogies that can load two 40 feet containers or three swap-bodies (or combinations of unit loads including High cubes) on an 80 ft loading area. It implies better loading factors of trains, 10 % more TEU per length on fewer axles, and thus lower energy consumption, less maintenance and lower cost per transported unit (VEL wagon 2012). Other measures are short-coupled wagons with draw-bars, or automatic couplers without buffers.

5.2 Axle load and freight train speed

The axle load of a wagon is the total wagon weight (empty wagon weight + load on the wagon) resting on the axle. Higher axle load means fewer requirements of wagons, which is good from the operator and customer point of view. Axle load is therefore an important design factor in the engineering of railways, designed to tolerate a maximum weight-per-axle (axle load). If it exceeds the maximum rated axle load, it will cause more damage to the track so, for infrastructure managers, a lower or safer axle load limit is desirable. In this regard [23] remind us that: 'the negative impacts of increased axle loads occur primarily in the areas of track and bridge maintenance and renewal, and freight car maintenance'.

The SUSTRAIL study (2014) puts a high priority on the improvement of the rail system as a whole and emphasises an increase in axle load limits (to 22.5 t / 25 t), depending on different operational scenarios [34]. Some infrastructures, usually ore lines, are designed and maintained for even higher axle loads than those suggested above. For example, heavy haul transport with axle loads up to 30 t is well developed in Sweden, although for specific circumstances that may not be copied to other railways in general. Advances in rail vehicle bogie and general rail vehicle dynamics, through better suspension characteristics, are expected to reduce direct damage to track and allow increasingly high axle loads. An increase of axle load on existing lines can be costly but, if this is done systematically at renewal of the lines, the marginal cost will often be small.

Studies such as [9, 27] report that railways in the USA have significantly higher axle loads than in Europe. Standard "free interchange" axle loading in the USA (and in North America in general) is 33 tonnes (36 tonnes) on 914 mm (36") diameter wheels. [23] suggest that to improve productivity 'there has been a constant pressure in the marketplace to increase train weight and axle loads in order to reduce operating costs and increase capacity' in the USA. They report that: 'The capacity of the average freight car has risen by about 80 % since 1960 and reached 92 tonnes'. This higher axle load, combined with longer trains, results in a significantly higher level of rail loading capacity (12,000+ tonnes per train). The example portrays that capacity on the North American railways has generally developed to meet a need. The question can be asked: how

relevant this is for European rail freight transport? Building such high capacity is costly and, given the trend in freight movement, is only necessary in Europe on a few, specialised routes e.g. the Iron Ore Line, known as 'Malmbanan', which is capable of transporting 32.5 tonnes axle-load between Narvik, in Norway and Kiruna, in Sweden.

Currently the maximum freight train speed is 100 km/h but, in Europe, freight trains are generally operated at a much lower average speed than inter-urban passenger trains. Many modern wagons and locomotives are designed for 120 km/h, but this speed is achieved only for some special trains. A higher speed will mean higher energy consumption but at the same time shorter transport time will improve the asset utilisation per unit of time. From a system perspective, more freight trains can be operated in between fast passenger trains, in the day time. The speed of normal freight trains was increased from 80 to 100 km/h, on many European networks, about twenty years ago. Considering this, the TEN-T regulations have set a target of achieving freight train speeds of 100 km/h on all European railways by 2030 [8]. The Europe wide incremental increase of speed can be conducted most economically if and when appropriate infrastructure and rolling stock are adopted.

5.3 Acceleration and braking

The normal braking system of freight trains is based on depression of a single brake pipe and its slow propagation towards the end of the train, successively putting all distributors into service when they detect the pressure drop. For that reason, the last wagons are still busy running while the first wagons are trying to stop, creating longitudinal compression forces that increase the risk of derailment. The time taken to brake a freight train is therefore quite long compared to a passenger train. At the same time as releasing the brakes, it is necessary to refill the brake pipe, until nominal pressure for each wagon to release the brakes is reached. The time to release the brakes is also quite extended. An improved braking system is therefore vital from a freight operator and infrastructure manager point of view, though a more drastic remedy would be to abolish this braking system and change to a high performance system that includes electro-pneumatic brakes, regenerative brakes and disc brakes [24, 33]. The operation of a higher speed freight train would imply the ability to exploit train paths of passenger train quality, in terms of acceleration, braking and line speed, and minimising the impact on following trains.

5.4 Loading gauge

High cubic and tonnage capacity per wagon are important aspects of freight train efficiency and capacity which can be limited by, among other things, permissible loading gauge and

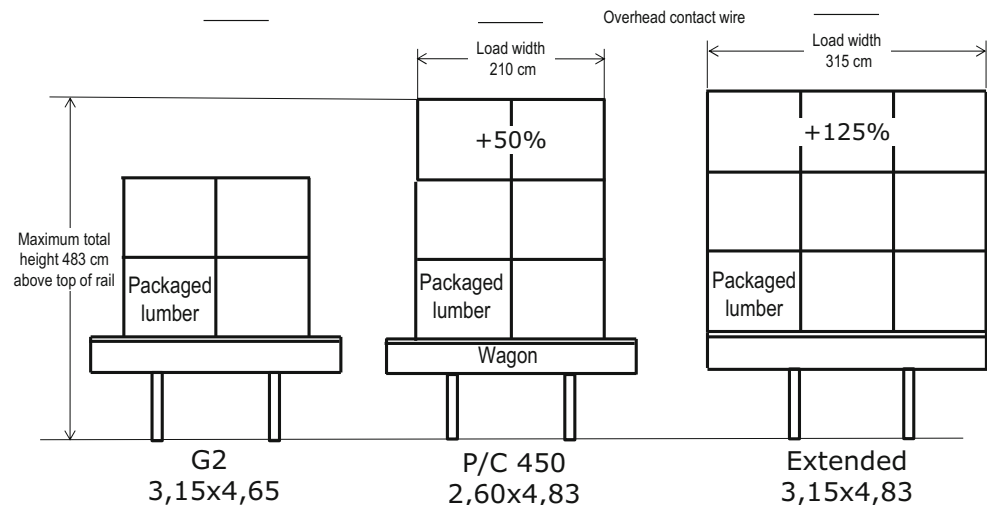
axle load [3]. A loading gauge can be defined as the maximum height and width of railway vehicles and their loads, to ensure safe passage through bridges, tunnels and other structures. A larger loading gauge is as important as a higher axle load/weight per metre and the greatest effect is often obtained by combining the two [33]. In Sweden, a very generous loading profile (C) is already being introduced, over most of the network. In contrast, British railways have some of the worst loading gauge restrictions in Europe, although some routes (e.g. Southampton port to West midlands, via Reading) have improved significantly in recent years [30]. It is very important to make the loading gauge rectangular, by removing the bevelled corners, which is sometimes simpler and important from a market perspective [3] (see Fig. 7). For trailer transportation, it is very important to have a high but not so wide loading gauge. [3] suggests that the loading gauge P/C 450 (4.83×2.60 m) is ideal, because it makes it possible to transport both 4.5 m high trailers on pocket wagons and 4.0 m high trailers on low, flat cars with a height of 0.83 metres. Extending loading gauge is generally costly, especially the height at tunnels or bridges, yet in Sweden the width of the loading gauge on many lines has been extended at small cost.

5.5 Train length and locomotive options for traction

Much of today's European freight train system has inherited an old standard 3–4 MW electric locomotive that can haul trains of approximately 1500 gross tonnes and a train length of 650–750 metres. However, modern locomotives have a tractive power of 5–6 MW, capable of hauling 2000–2500 tonne trains of up to 1050 m in length. The length of freight trains on European railways varies significantly from country to country and, on some railways, 850 m long trains are running. Moreover, in 2014 experiments were conducted with 2×750 m = 1500 m long trains, with radio-controlled locomotives in the middle of the train set [31, 36]. However, the TEN-T Regulation suggests a 740 m long train with 22.5 tonnes axle load, on European core networks, by 2030 [8]. To operate longer trains, the extension of tracks at sidings, crossing stations and terminals is needed. This is costly - but often less costly than building more double tracks, or new lines.

Regarding energy supply source, a locomotive can be diesel, electric, or combined. There are significant differences in the energy efficiency - and thus operational cost and emissions - of the rail freight system. Electric locomotives are the best choice from an environmental and economic point of view, although questions remain as to how the electricity is produced, as electricity generated from a coal-fired power plant will have produced substantial emissions compared to a hydropower plant with very low or no emissions. The energy efficiency of an electric locomotive can be improved by optimising its operational efficiency. The energy supply to the rolling stock can be improved by electrification of existing

Fig. 7 Possibilities to load more freight on existing wagons [5]



diesel-operated railway lines, as well as by a low greenhouse gas (GHG) producing production source. Approximately 55 % of the European rail network is electrified and 85 % of freight traffic is handled by electric traction. Electric locomotives are often used for long distance transport between marshalling yards, but diesel locomotives are used to distribute the wagons to customers, because their tracks are often non-electrified. Duo-locomotives are now available on the market which have both electric and diesel traction. This allows train operators to run a service with one locomotive instead of two, reducing investment and capital costs and making operations more responsive, for example by shunting wagons on non-electrified sidings along the line. In the long term perspective, duo-locomotives can be profitable even if they are a little bit more expensive than ordinary locos.

5.6 Improved transshipment

The efficiency and effectiveness of rail freight services is largely dependent on the efficiency and effectiveness of terminals, marshalling yards along the transport chain, and feeder transports. Transshipment in terminals is traditionally performed vertically, using a variety of equipment, such as Transtainer (gantry crane), Reach Stacker, Straddle carrier, or Fork lift. With this type of equipment, a container is lifted from a train and moved to a stack yard, either for storage, or loading onto a truck, etc. Comparatively speaking, this vertical transshipment is costly, time consuming and incurs a higher risk of loss/damage to cargo. Moreover, 80 % of European trailers cannot be lifted, restricting market share.

Modal transfer points need methods and technologies that cost less and are less time consuming. Along these lines, the [33] study suggests horizontal transfer of the cargo unit, using comparatively cheaper transshipment equipment and taking up less space - and therefore cost - for trucks and trains. The cargo truck can be placed parallel to, and virtually next to, the

railway line (see Fig. 8), for easier loading of wagons. This type of transshipment, classified as a small terminal, will allow train operators to stop at comparatively shorter intervals to pick up or deliver a smaller number of containers, or swap bodies. The operation of such terminals also requires fewer staff, while allowing faster pick up of cargo from origin and delivery to destination. Moreover, there is no need for a diesel engine to shunt the wagons into the terminal, and little or no need for track to store (waiting) wagons.

A small-scale intermodal freight train system has been implemented in Switzerland. Innovatrain - a liner train with stops at many terminals over short distances - is a push-pull train capable of operating in either direction [21]. It can either run on the electrical main track, at speeds up to 120 km/h, or drive into a private railway siding by using its diesel power. For horizontal transshipment, the ContainerMover system is used, between the train and the truck. The device is mounted on the truck, which makes transshipment possible at every terminal, or small terminal/ siding. Another system for horizontal transfer of unit loads is the CarConTrain (CCT), consisting of a wagon that travels parallel with the track, equipped with arms for transferring freight horizontally [28]. The system can transfer unit loads fitted with corner castings from 2.5 to 3.6 metres wide and 3 to 12 metres long. Since it can be fully automated, it could be used in unmanned terminals and warehouses. The train can be unloaded regardless of whether the truck is available and can arrive at any time, since no personnel are required. The terminal cost can be reduced and thus the cost of the overall transport chain.

Shuttle freight trains - by their nature direct - generally run between hubs where multiple wagons are consolidated or unbundled for different destination terminals [25]. The shuttle trains generally run with scheduled path allocations. The rail terminals may be linked with services such as marshalling yards, for consolidating SWLs. Thus, an efficient and effective operation of marshalling yards is at the heart of the future

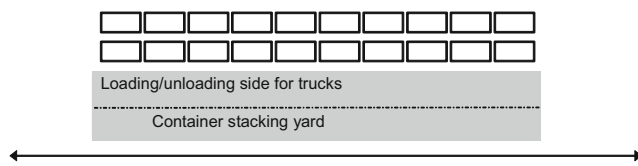


Fig. 8 Typical trackside low-cost loading/unloading facility. Source: (SPECTRUM [32, 33])

SWL and other types of freight service in Europe. Instead of a conventional hub and spoke system, we can consider a system of liner trains - a similar concept to liner shipping - where the trains run on a main route and wagons are picked up and dropped at stations along the way.

6 Summary and conclusion

Achieving modal shift from road to rail will rely on a mixture of both customer and market related requirements and the necessary associated improvements to the EU's rail systems. Much of today's freight rail system is based on an old standard 3–4 MW locomotive, which means trains of 1500 gross tonnes and a length of 650–750 metres. However, modern locomotives have a tractive power of 5–6 MW, capable of hauling 2000–2500 tonne trains, of up to 1000 m in length. In Europe, train lengths up to 850 m are already in operation and experiments have been made with $2 \times 750 \text{ m} = 1500 \text{ m}$ long trains. With a higher axle load, the operation of heavier trains can be achieved. Duo-locomotives have been introduced, equipped with both normal electric traction and diesel traction, which can shunt wagons at a marshalling yard, or in an un-electrified siding. Operators thus need only one loco instead of two, also making it possible to introduce liner trains that can stop along the line and change wagons.

Concerning wagons, the question is whether development will be incremental or if it is possible to make a system change (see Table 1). An incremental change means successively higher axle loads, wider gauge, higher payload, better and more silent brakes and some electronic equipment. A system change will include electro-pneumatic brakes, disc brakes (from cast brakes) and full electronic control (from pneumatic) of wagons and load, and automatic central couplers (from screw couplers). Automatic couplers are the most critical component, not only to make shunting and marshalling safer and cheaper, but also because this will make it easier to operate longer trains. However, to introduce automatic couplers it must be supported by a thorough cost-benefit analysis.

For an intermodal service, the terminal cost and time are critical. If terminals are located on an electrified side track, where the train can drive straight in and out, liner trains can be used without switching to a diesel engine. This process speeds up by adopting a horizontal transfer technology that can function under overhead contact wires and facilitate faster

loading/unloading of containers, resulting in a short stoppage time (aspiring to 20–30 min) in terminals. The terminals can be compact, as there is little or no need for storage tracks. Most trailers currently in use are not designed to be lifted onto a railway wagon, so solutions must be found to roll trailers on and off; this will considerably widen the market opportunity.

To increase the capacity of the rail system, the current study recommends the following measures, in ascending order of cost:

1. More efficient timetable planning: e.g. double track - bundling of trains with the same average speed in the timetable channels and daytime operation of faster freight trains.
2. Use of trains and vehicles with higher capacity: higher utilisation of existing trains, longer trains, higher and wider gauge, higher axle load and metre load.
3. Differentiation of track access charges to avoid overloaded links.
4. Better signalling systems, such as ERTMS, with shorter block lengths.
5. Adaptation of Rail Freight Corridors for longer and heavier freight trains. Longer and heavier trains will make it possible to roughly double the capacity.
6. Investment in high speed rail to increase capacity for freight trains and regional trains on both the conventional network and on dedicated freight railways (see Fig. 9).

A general problem is that investments in rolling stock often are done by operators from a business perspective and investments in infrastructure often are done by the state from a socio-economic perspective. That means that there is a need for co-ordination to optimize the system.

An estimation of the effects of a modal shift to rail transport, by applying the world's 'best practice', shows a reduction in EU land transport GHG emissions of 20–30 %,

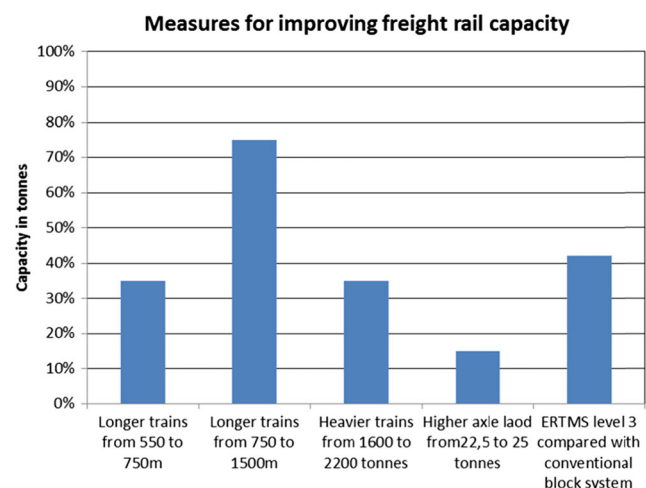


Fig. 9 Capacity gains for different freight train measures in tonnes per train taken line capacity into account. Source: [37]

compared with a ‘business as usual’ scenario. The rail system can thus substantially contribute to the EU target to reduce GHG emissions in the transport sector by 60 %, compared to 1990 levels. To enable such a mode shift there is a need for strong development of the rail system.

The authors contend that service quality can be improved by better planning, the application of appropriate ICT-systems (e.g. ERTMS, web-based tracking and tracing system, incorporating all transport chain partners) and the adoption of an integrated supply chain approach to meet customer requirements. A more customer-orientated service offering can also be achieved by further deregulation of rail. Each of these suggested measures needs further in-depth research.

There are however also problems in implementing new standards in the rail sector, as investments are often costly and the life cycle of infrastructure and rolling stock is very long. There is a need to discuss future standards at an early stage, as we have done here, but also to perform the commercial and socio economic evaluation that is outside the scope of this paper.

The research notes, with due importance, the need to reduce the operational and investment costs of rail, which can act as a powerful enabler of modal shift. Two ways this might be facilitated are:

- By better competition in rail business. This needs further research and development, as aspired to in the Shift2Rail public–private initiative undertaken by the rail industry and the EU.
- By appropriate and carefully developed cost-benefit analysis of measures, prior to their implementation.

Particularly important to lowering operational cost and offering a lower freight rate are: the operation of heavier and longer trains; wider loading gauge; higher average speed; and better utilisation of wagon space and all assets. Improved intermodal transshipment will also be vital to improving quality and gaining a more available and punctual customer service.

Future research, to be reported in a subsequent paper, will conduct cost-benefit analysis (that includes socio-economic aspects) and financial analysis (that takes commercial aspects into consideration) by exploring, in-depth, a variety of rail terminal operations to validate proposed new equipment, methods and standards, in terms of technologies and operational measures.

Acknowledgments The authors thank the European Commission for part-funding the research under the 7th Framework Programme, within the project “CAPACITY4RAIL: Increasing Capacity 4 Rail networks through enhanced infrastructure and optimised operations.” The authors would also like to thank all consortium partners, in particular WP2.1 partners, and the peers who provided constructive criticism and opinion that have improved the quality and content of the paper. The content and the opinions expressed in this article are the full responsibility of the authors.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

1. Ballis A, Golias J (2004) Towards the improvement of a combined transport chain performance. *Eur J Oper Res* 152(2):420–436. doi: [10.1016/S0377-2217\(03\)00034-1](https://doi.org/10.1016/S0377-2217(03)00034-1)
2. Boysen H (2012) General model of railway transportation capacity. In: 13th International Conference on Design and Operation in Railway Engineering (Comrail). doi: [10.2495/CR120281](https://doi.org/10.2495/CR120281)
3. Boysen H (2013a) Developing larger loading gauges for Europe. In: World Congress on Railway Research, (pp. 1–10). Sydney Australia
4. Boysen H (2013b) Øresund and Fehmarnbelt high-capacity rail corridor standards. In: 10th International Railway Engineering Conference (pp. 1–27). ECS Publication, London
5. Capacity4Rail Project (2014) Requirements toward the freight system of 2030/2050 - Intermediate report, Deliverable 21.1
6. Choi D-W, Menghrajani E (2011) Can group discussion promote cooperative ultimatum bargaining? *Group Processes Intergroup Relat* 14:381–398. doi: [10.1177/1368430210376404](https://doi.org/10.1177/1368430210376404)
7. Community of European Railway and Infrastructure Companies (2013) Rail freight status report 2013 rail freight after a decade of EU rail policy. Retrieved from <http://www.cer.be/>
8. Community of European Railway and Infrastructure Companies (2014) Annual Report 2013–2014. Brussels
9. D-RAIL (2012) Rail freight forecast to 2050. Newcastle upon Tyne: NewRail, Newcastle Centre for Railway Research, Newcastle University
10. European Commission (2001) White Paper European transport policy for 2010 : time to decide. Brussels
11. European Commission (2011) Transport White Paper - roadmap to a single European transport area – towards a competitive and resource efficient transport system. European Commission, Brussels
12. European Commission (2013) EU Transport in figures Statistical pocketbook 2013. Publications Office of the European Union, Brussels. doi: [10.2832/19314](https://doi.org/10.2832/19314)
13. European Commission (2014) EU Transport in figures - statistical pocketbook 2014. Retrieved from http://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2014_en.htm
14. IBM Global Business Services (2011) Rail liberalisation index 2011
15. Islam D, Dinwoodie J, Roe M (2005) Towards supply chain integration through multimodal transport in developing economies: the case of Bangladesh. *Marit Econ Logist* 7(4):382–399. doi: [10.1057/palgrave.mel.9100144](https://doi.org/10.1057/palgrave.mel.9100144)
16. Islam D, Zunder T, Zomer G (2010) The potential of a pan European rail freight service using hub and spoke model. *Int J Logist Transp* 4(2):21–30
17. Islam D, Jackson R, Zunder T, Laparidou K, & Burgess A (2013) Triple rail freight demand by 2050 in EU27- realistic, optimistic or farfetched imagination? In: 10th World Congress on Railway Research. Sydney, Australia
18. Islam D, Zunder T, Jorna R (2013) Performance evaluation of an online benchmarking tool for European freight transport chains. *Benchmarking: Int J* 20(2):233–250
19. Islam D, Jackson R, Zunder T, Burgess A (2015) Assessing the impact of the 2011 EU Transport White Paper - a rail freight

- demand forecast up to 2050 for the EU27. *Eur Transp Res Rev* 7(77):1–9. doi:[10.1007/s12544-015-0171-7](https://doi.org/10.1007/s12544-015-0171-7)
20. Jackson R, Islam D, Zunder T, Schoemaker J, Dasburg N (2013) A market analysis of the low density high value goods flow in Europe. In: World Conference on Transport Research 13. Rio, Brazil
 21. Jackson R, Matsika E, Zunder T, Mahler S (2013) Conceptualisation of an Innovative Rail Freight Vehicle for Transporting LDHV Cargo in an EU Context. In: WCTR Sydney
 22. Jackson R, Islam D, Zunder T, Schoemaker J, Dasburg N (2014) A market analysis of the low density high value goods flows in Europe. In: Selected Proceedings: 13th World Conference on Transport Research (WCTR). 2014, Rio de Janeiro: COPPE - Federal University of Rio de Janeiro, Brazil., In: Select, 1–12
 23. Kalay S, Lopresti J, Davis D (2011) Development of enabling technologies for heavy axle load operations in North America. In: 9th World Congress on Railway Research. Lille, France, p 1–12
 24. Kreutzberger E, Macharis C, Vereecken L, Woxenius J (2003) Is intermodal freight transport more environmentally friendly than all-road freight transport? A review. In: NECTAR Conference No 7, Umeå, Sweden June 13–15, pp 1–22
 25. Mangone A, Ricci S (2014) Modeling of port-freight village systems and loading units' tracing functions. IF - Ingegneria Ferroviaria, 1.
 26. Meleady R, Hopthrow T, Crisp RJ (2012) The group discussion effect: Integrative processes and suggestions for implementation. *Pers Soc Psychol Rev* 17(1):56–71. doi:[10.1177/1088868312456744](https://doi.org/10.1177/1088868312456744)
 27. Mortimer P, Islam DMZ (2014) A comparison of North American and European railway systems – a critique and riposte. *Eur Transp Res Rev*. doi:[10.1007/s12544-014-0148-y](https://doi.org/10.1007/s12544-014-0148-y)
 28. Nelldal B-L (2013) Roadmap for development of rail and intermodal freight transportations - High Capacity Transport for rail, The Green Freight Train, KTH TRITA-TSC -RR 13–006. Stockholm
 29. Nelldal B-L, Andersson E (2012) Mode shift as a measure to reduce greenhouse gas emissions. Paper 635at. In: Transport Research Arena 2012. Athens
 30. Network Rail (2014) Control period 4 freight review
 31. NEWOPERA (2014) 1. 5 KM marathon train successfully tested. *newopera*. Retrieved from <http://www.newopera.org/node/112>
 32. SPECTRUM Consortium (2012) Market based operational requirements for new rail freight services, Final Deliverable D1.2 (Vol. 2012). Newcastle upon Tyne. Retrieved from WWW.SPECTRUM.INFO
 33. SPECTRUM Consortium (2013) Deliverable D2.4 Concepts
 34. SUSTRAIL consortium (2014) Hybrid locomotive deliverable D3.2.1
 35. TOSCA (2011) Scenarios of European Transport Futures in a Global Context, Deliverable D8 -WP 6 . 1 report (Vol. 8)
 36. Toubol A, Castagnetti F (2014) Marathon project for long trains with distributed traction. In: Transport Research Arena 2014. Paris
 37. TRANSFORUM (2014) Transforum Transport 2050: long distance freight roadmap. TRANSFORUM Project Roadmaps. Retrieved December 8, 2014, from www.transforum-project.eu
 38. Tsamboulas D, Vrenken H, Lekka A (2007) Assessment of a transport policy potential for intermodal mode shift on a European scale. *Transp Res A Policy Pract* 41(8):715–733. doi:[10.1016/j.tra.2006.12.003](https://doi.org/10.1016/j.tra.2006.12.003)
 39. Woroniuk C, Marinov M, Zunder TH, Mortimer P (2013) Time series analysis of rail freight services by the private sector in Europe. *Transport policy*, 25(null), 81–93. Retrieved from doi:[10.1016/j.tranpol.2012.09.004](https://doi.org/10.1016/j.tranpol.2012.09.004)
 40. Zunder TH, Islam DMZ, Mortimer PN, Aditjandra PT (2013) How far has open access enabled the growth of cross border pan European rail freight? A case study. *Res Transp Bus Manag* 6:71–80. doi:[10.1016/j.rtbm.2012.12.005](https://doi.org/10.1016/j.rtbm.2012.12.005)